LESSON 6

TOPIC 1

Embankment Settlement

EMBANKMENT SETTLEMENT

Lesson 6 - Topic 1

Slide 6-1-1

Introduce the settlement lesson and indicate that the lesson will be broken into two parts; first the settlement analysis procedures will be covered then the treatments for settlement will be covered second.

EMBANKMENT SETTLEMENT

1. Estimate Compressibility from Basic Soils Data
2. Calculate Settlement

ACTIVITIES: Compressibility Values
Settlement Analysis

Slide 6-1-2

Lesson objectives

Embankments
Major Design Considerations

- ***Stability***
- ***Settlement***
- ***Effects on the Structure***

Slide 6-1-3

Review that stability issues must be considered first, then settlement and the effects on structures complete the embankment design.

Embankments

- ***End Slope Safety Factor = 1.30***
- ***Side Slope Safety Factor = 1.25***

Slide 6-1-4

Review safety factors required for acceptable stability conditions.

Slide 6-1-5

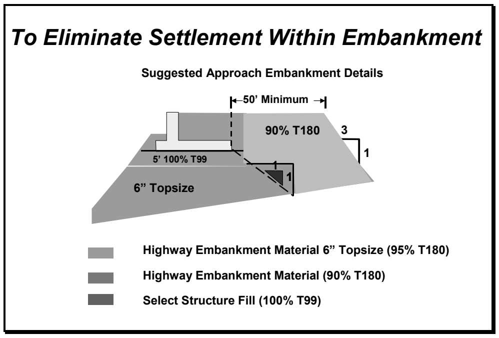
Case history of settlement within embankment. As indicated by adjacent ground topography, this embankment was placed on rock. However note that so much settlement and regrading/repaving has occurred that the guardrail is nearly at pavement level.

Avoid Settlement Within Embankment

- ***No Organic or Miscellaneous Fill Material Allowed***
- ***Control Fine-Grained Material Use***
- ***Require Compaction and Compaction Control Tests***

Slide 6-1-6

Internal consolidation factors.



Slide 6-1-7

Typical cross section of good design to prevent internal consolidation.

Slide 6-1-8

Typical case history of the bump at the end of the bridge. Note the characteristic dip in the guard rail and the patch at the interface between the abutment backwall and the approach fill.

Reasons for "the Bump at the End of the Bridge"

- ***Poor Compaction of Embankment Material Near the Structure***
- ***Migration of Fines into Drainage Material Behind Abutment Backwall***

Slide 6-1-9

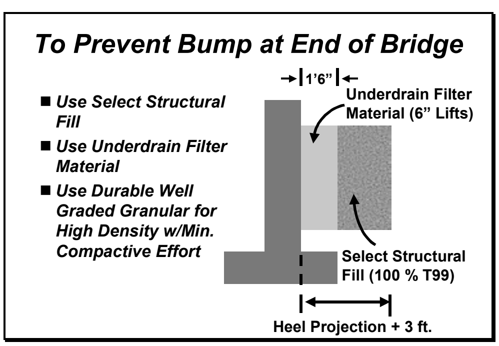
State reasons, and then asks audience how their highway agency prevents the bump at the end of the bridge. The answer you want is "use an approach slab". After either getting that answer or leading the audience to the answer, show the next slide of an approach slab

Slide 6-1-10

Note the use of the slab has only moved the bump to the end of the approach slab. This is not the most effective method to eliminate the bump.

Slide 6-1-11

In order to understand the source of the problem of the bump at the end of the bridge you need to understand the typical construction process for a bridge abutment in fill. Note in this photo the main height of fill only extends partially into the U-shape of the abutment. The final backfill will be placed when the forms are stripped. Note that the backfill area is narrow, the corners cramped and the backfill will be placed against both the back wall and the slope. Proper materials and placement are needed to ensure a non-yielding backfill that will withstand years of drainage from the bridge and the heavy impact of trucks rolling off the bridge.



Slide 6-1-12

Show the recommended solution in cross section and highlight important items to be included in the specifications. Emphasize durability and ask what controls the agency now has on durability of backfill.

Select Material Specifications

- ***Specification Item***
  - *6”-8” Lift Thickness*
  - *Topsize Restriction*
  - *Gradation Requirement*
- ***Reason for Item***
  - *Small Compaction Equipment*
  - *Less than 3/4 Lift Thickness*
  - *Compactibility*

Slide 6-1-13

Focus on what should be included in the specifications and the reason for the item.

Select Material Specification (Cont’d)

- ***Specification Item***
  - *Durability*
  - *Limit Percent Fines*
  - *T99 Density Control*
  - *Compatible to Drain Material*
- ***Reason***
  - *Minimize Breakdown*
  - *Density/Piping*
  - *Small Compaction Equipment*
  - *Prevent Piping*

Slide 6-1-14

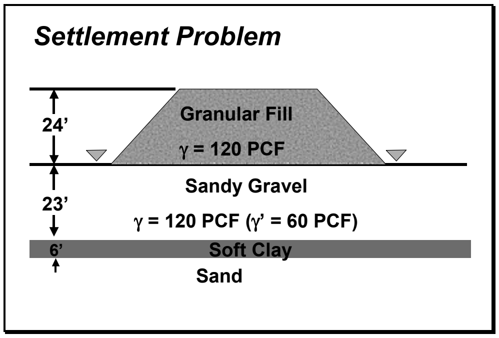
Focus on what should be included in the specifications and the reason for the item.

Avoid Major Subsoil Settlement

- ***Identify and Provide Treatment for Organic Soils***
- ***Analyze Clay Subsoil Deposits***

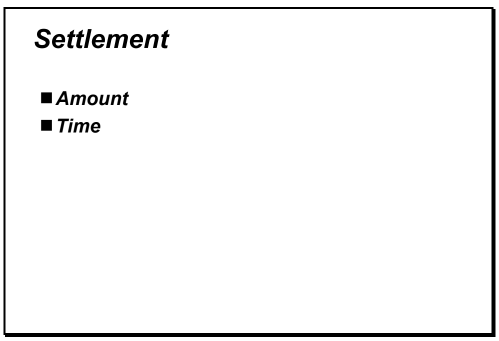
Slide 6-1-15

Begin the analysis portion of subsoil settlement here. Start slowly by building on basic concepts until the student has been shown the entire settlement computation and analysis process over a series of visuals. First introduce the concept of subsoil settlement.



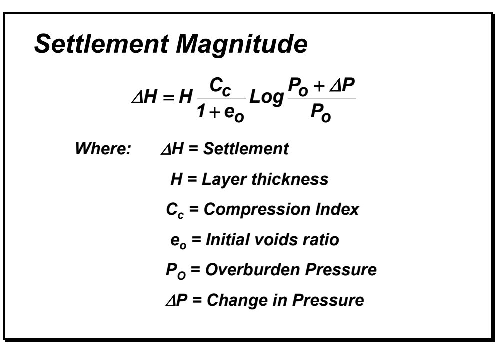
Slide 6-1-16

Show typical problem where subsoil settlement is the main issue. Ask which layer is of most concern to consolidate (clay layer). Then ask what two steps need to be taken before a designer can accurately predict the settlement (take undisturbed tubes in the clay layer and perform consolidation tests).



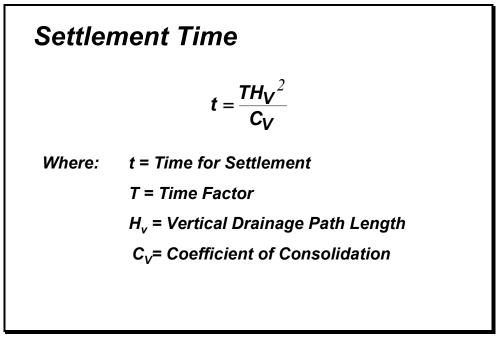
Slide 6-1-17

Stress that time as well as magnitude must be considered. Stress that the time for settlement is a very important issue for post construction maintenance of the highway facility. Periodic road closure for maintenance result in expenditure of highway funds, delays to traveling public, and bad public relations for the agency. Funds are better spent to assure a adequate design than to repair a poor design.



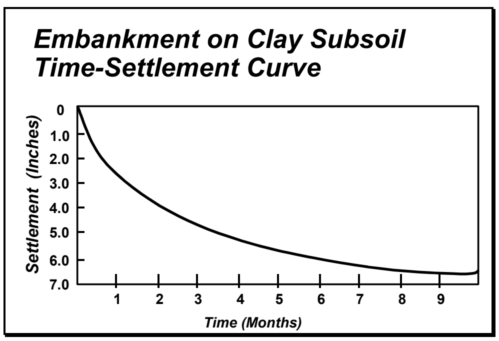
Slide 6-1-18

Introduce and explain the basic settlement equation. Emphasize the need for good consolidation testing. Ask students how to find each of the terms in the equation (H from soil profile, C_c and e_o from consolidation test, Po from Po diagram and change in pressure from applied load.



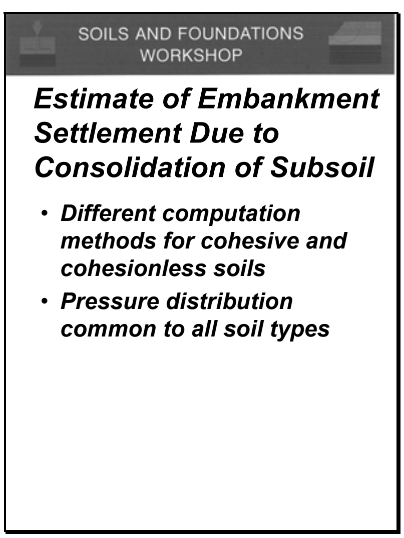
Slide 6-1-19

Introduce and explain the time equation with emphasis on determination of the vertical drainage path and how this value may not be the same as the layer thickness.



Slide 6-1-20

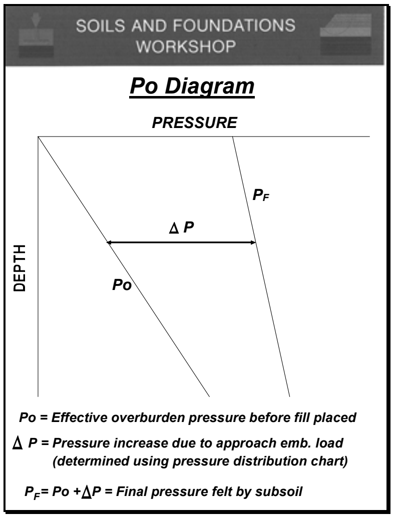
Show the results of a typical time –settlement analysis and explain how to use this in project design. Mention that time for settlement is often over-predicted from the results of consolidation tests due unforeseen lateral drainage or disturbance of the test sample. Plant the seed for the use of instrumentation to measure the actual rate of consolidation during construction.



Slide 6-1-21

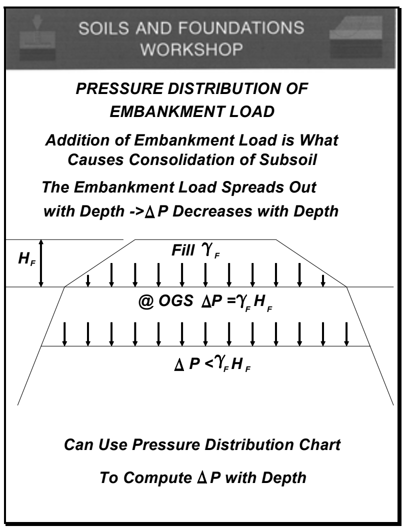
Instructor should use overhead transparencies for the remainder of this topic.

Explain that different computation methods are used for cohesive and granular soils but that pressure distribution is the same for both.



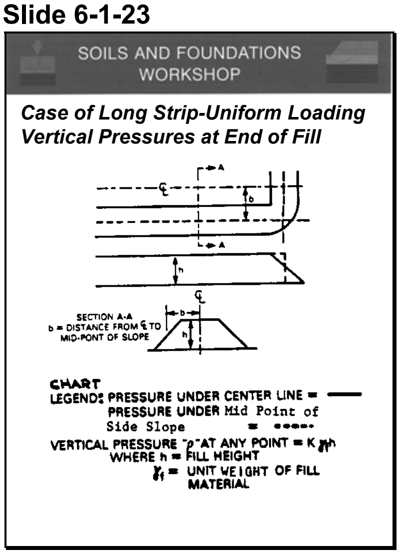
Slide 6-1-22

Show the Po diagram with an added entry of the distribution of pressure with depth. Important to state that pressure at various levels below ground is less than the pressure applied at the ground due to pressure distribution.



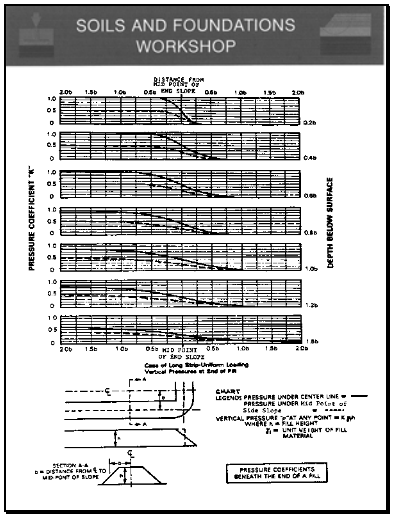
Slide 6-1-23

Stress that distribution depends only on the extent of the load area. The wider and longer the area of load; the greater the pressure at depth below ground. Note that discontinuities in loaded area (such at locations where the embankment stops and the bridge begins), can cause difficulties in finding how pressure is distributed with depth.



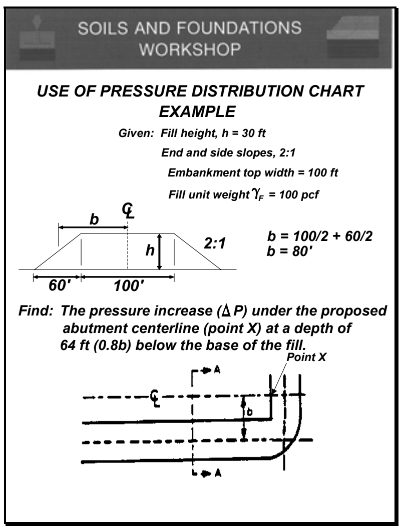
Slide 6-1-24

Until now, we have assumed only a condition where the fill is continuous in length. However in the case of end fills at bridges, the pressure distribution will be affected by the discontinuous fill. Pressures near the toe of fill are less than pressures beneath the top of fill. The term “b” which represents the half-width of the fill can be used to determine the variation of pressure both below ground and at distances along the length of the end fill.



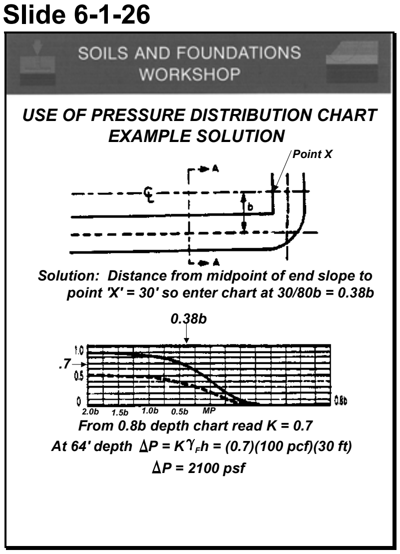
Slide 6-1-25

Show the end fill pressure distribution chart. This is the most difficult chart to grasp in the course and requires a slow, in-depth explanation; particularly of “b” which is the term which relates the extent of the loaded area to distribution.



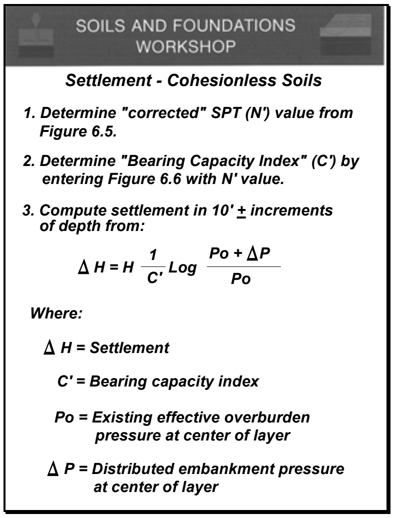
Slide 6-1-26

Explain the example with emphasis on the importance of the “b” term and how you computed the ‘b’ term. To be 80’. Then return to previous slide. Show students that the depth below ground can now be determined for each chart, (0.2b, 0.4b, etc.). Now the charts are for depth of 16’, 32’, 48’, 64’, etc. Then show next slide to illustrate the computation of ‘k’ at the 64’ depth.



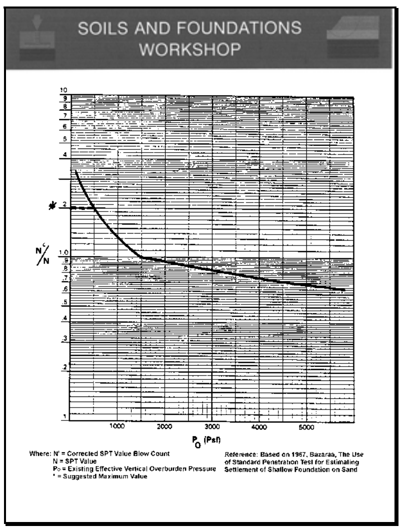
Slide 6-1-27

Explain the solution



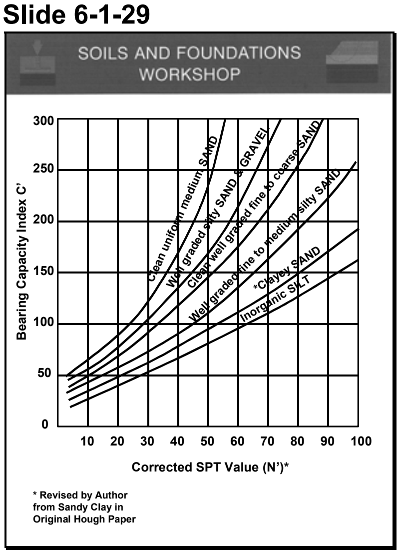
Slide 6-1-28

Overview the granular settlement computation process.



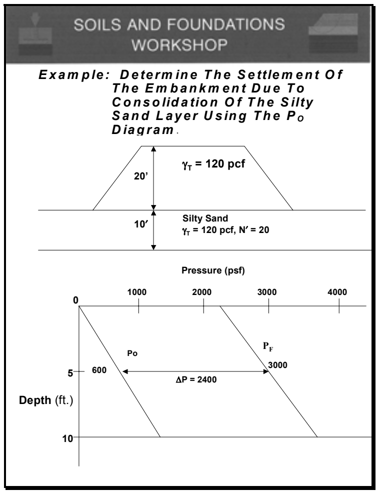
Slide 6-1-29

Explain why field N values need to be corrected.



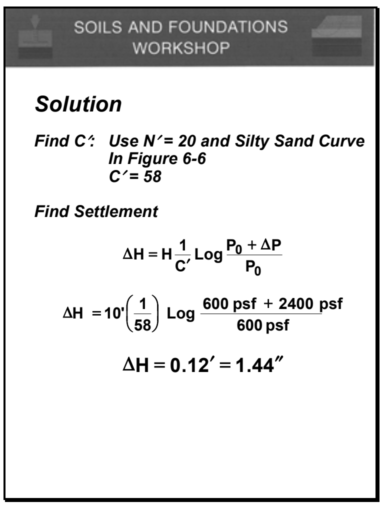
Slide 6-1-30

Explain how soil type affects compressibility. Remind Students of the relative volume solids and volume of voids for different soil types shown in lesson 4. Fine-grained soils consolidate more than coarse-grained soils. Note that original ASCE paper shows sandy clay but author probably meant to use clayey SAND.



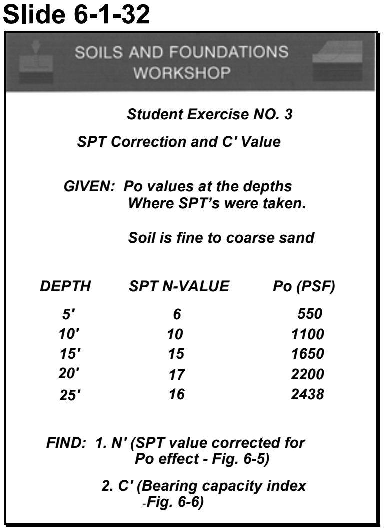
Slide 6-1-31

Instructor demonstrates granular settlement computational process in an example.



Slide 6-1-32

Instructor demonstrates granular settlement process in an example. Then go to the reference manual and point out where these figures are located.



Slide 6-1-33

Student exercise to find compressibility value for granular soils from both the field blow count and the soil visual from the lab. The purpose of the exercise is to show how the field value must be corrected for overburden pressure and the soil type identified before compressibility values can be found. The emphasis of the exercise is on the need to get quality input data for settlement analyses. The next example will extend the results into a settlement computation. After student exercise complete, ask for team to put results on flip chart or divide exercise into segments with team 1 computing only 5' depth values, team 2–10' values, etc. Then instructor asks teams for answers and write on flip chart. Ask team how results would have been affected if soil type were sand and gravel, or inorganic silt.

Please refer to the end of the lesson for this exercise.

SOILS AND FOUNDATIONS WORKSHOP

Solution to exercise No. 3

Depth	N	Po (psf)	N′/N	N′	C′
5	6	550	1.90	11	48
10	10	1100	1.28	13	52
15	15	1650	0.98	15	58
20	17	2200	0.92	16	60
25	16	2438	0.88	14	57

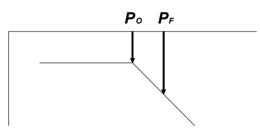
Slide 6-1-34

Show answers to student exercise.

Please refer to the end of the Participant Workbook for the solution to this exercise.

SOILS AND FOUNDATIONS WORKSHOP

Settlement Estimate - N.C. Clay



$$\Delta H = H \frac{Cc}{1 + e_o} \text{Log} \frac{P_F}{P_O}$$

H = Thickness of clay layer

Cc = Compression index (e-log P curve)

e_o = Initial void ratio of clay

P_o = Existing effective overburden pressure (psf) @ center of layer

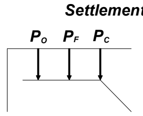
P_F = Final effective pressure ($P_o + \Delta P$)

Slide 6-1-35

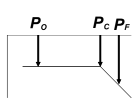
Introduce the computation of settlement in cohesive soils by starting with normally consolidated clays. Relate back to lab testing lesson on consolidation.

SOILS AND FOUNDATIONS WORKSHOP

Settlement Estimate - O.C. Clay



$$\Delta H = H \frac{Cr}{1 + e_o} \text{Log} \frac{P_F}{P_O}$$



$$\Delta H = H \frac{Cr}{1 + e_o} \text{Log} \frac{P_C}{P_O} + H \frac{Cc}{1 + e_o} \text{Log} \frac{P_F}{P_C}$$

H = Thickness of clay layer

Cc = Compression index (e-log P curve)

Cr = Recompression index

e_o = Initial void ratio of clay

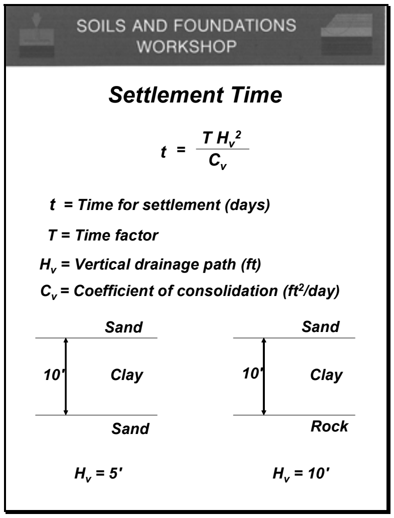
P_o = Existing effective overburden pressure (psf) @ center of layer

P_c = Preconsolidation pressure

P_F = Final effective pressure ($P_o + \Delta P$)

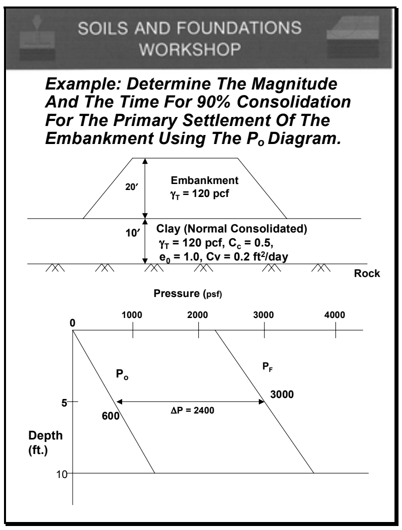
Slide 6-1-36

Discuss the method to estimate settlement in overconsolidated clays. Note that two computations may be necessary if the range of the change in pressure extends from P_o to above P_c.



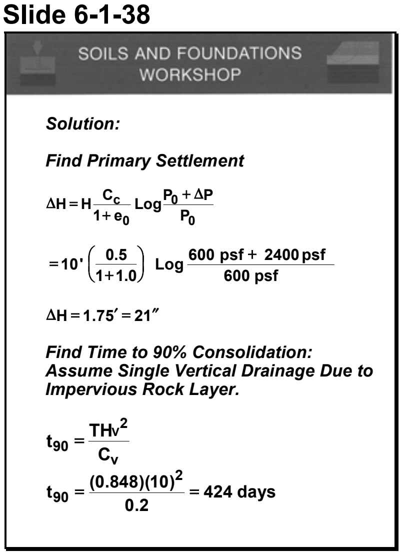
Slide 6-1-37

Introduce the computation for settlement time in clay soils. Then go to reference manual and review up to page 6-15.



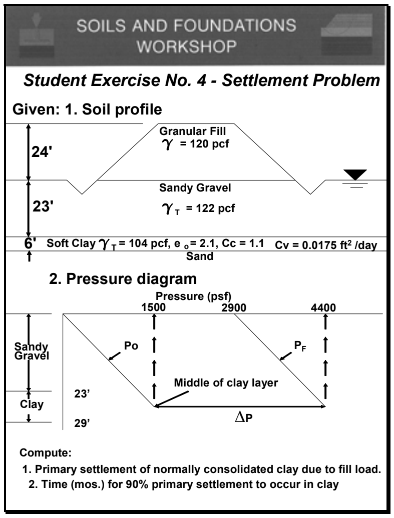
Slide 6-1-38

Demonstrate the computation process for clays. Build on the learned concepts from exercise on overburden pressure and the need for good consolidation data.



Slide 6-1-39

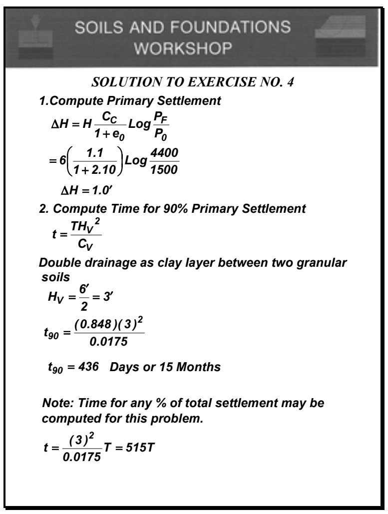
Instructor should solve this example by hand using a blank transparency. Show the solution to the clay settlement problem.



Slide 6-1-40

Student exercise on settlement in clay. The purpose of the exercise is to test learning of the settlement analysis process. The final question to the group after the analysis has been completed is "How accurate do you think this analysis is?" The answer is that depends on the quality of the data from the lab or the field. This recurring theme should be used in all exercises to continually reinforce the need for good data. Instructor demonstrates EMBANK software program. After student exercise, ask a team to put solution on the flip chart. Ask how time would be affected if the layer of clay were 12' thick?

Please refer to the end of the lesson for this exercise.

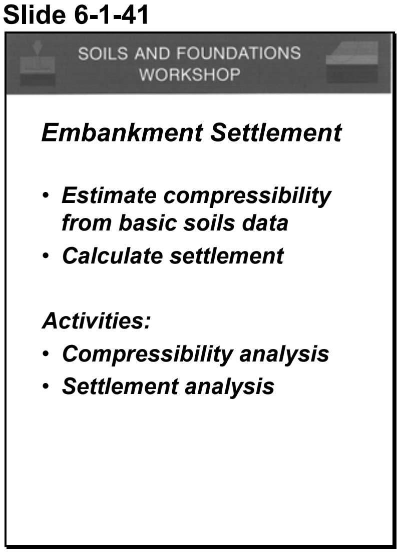


Slide 6-1-41

After student exercise, ask a team to put solution on the flip chart. Ask how time would affected if the layer of clay were 12' thick?

Instructor demonstrates EMBANK software program.

Please refer to the end of the Participant Workbook for the solution to this exercise.



Slide 6-1-42

Repeat objectives for lesson 6 topic 1.

SOILS AND FOUNDATIONS WORKSHOP

Student Exercise NO. 3

SPT Correction and C' Value

GIVEN: Po values at the depths Where SPT's were taken.

Soil is fine to coarse sand

DEPTH	*SPT N-VALUE*	*Po (PSF)*
5'	6	550
10'	10	1100
15'	15	1650
20'	17	2200
25'	16	2438

FIND: 1. N' (SPT value corrected for Po effect - Fig. 6-5)

2. C' (Bearing capacity index -Fig. 6-6)

SOILS AND FOUNDATIONS WORKSHOP

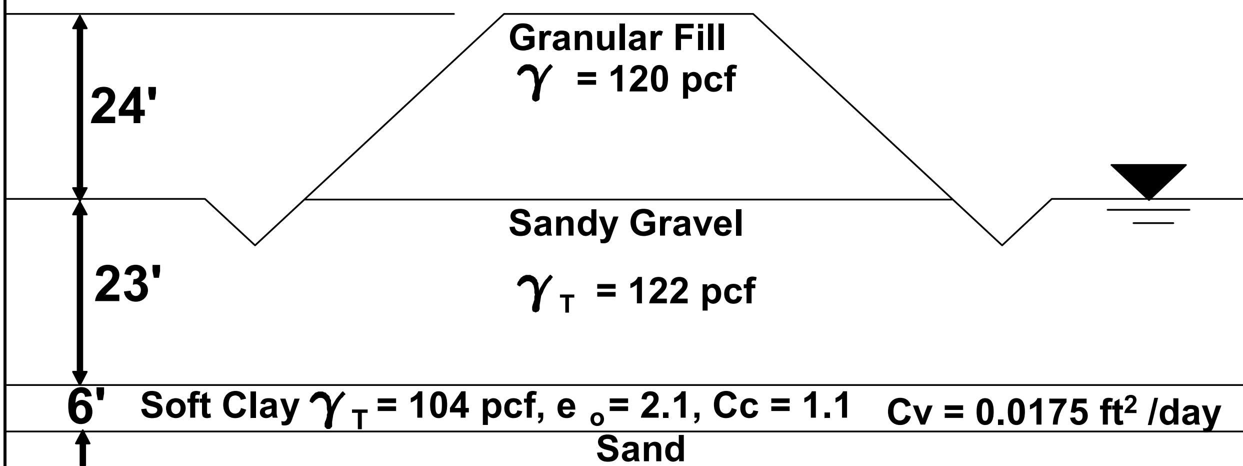
Solution to exercise No. 3

Depth	N	Po (psf)	N′/N	N′	C′
5	6	550	1.90	11	48
10	10	1100	1.28	13	52
15	15	1650	0.98	15	58
20	17	2200	0.92	16	60
25	16	2438	0.88	14	57

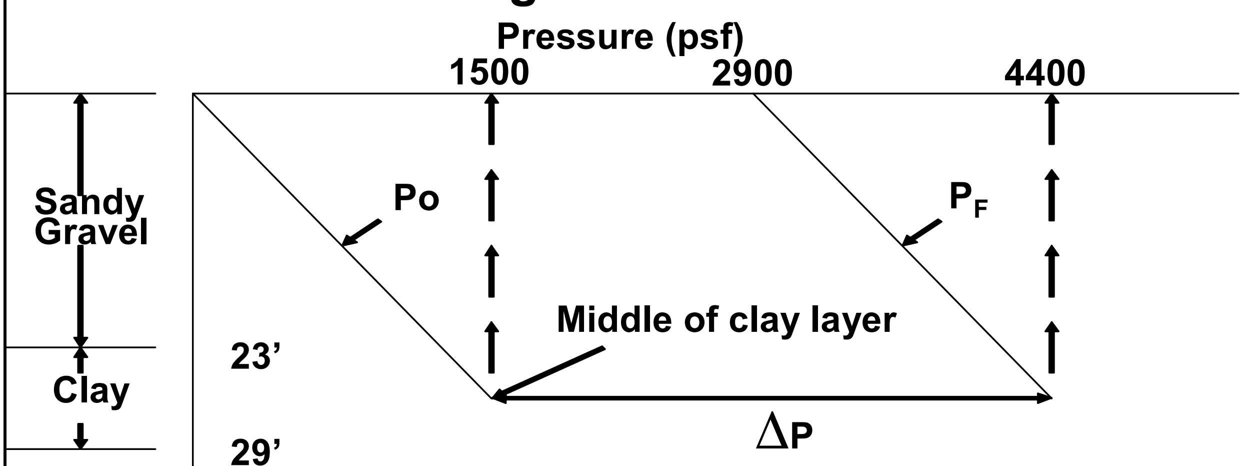
SOILS AND FOUNDATIONS WORKSHOP

Student Exercise No. 4 - Settlement Problem

Given: 1. Soil profile



2. Pressure diagram



Compute:

1. Primary settlement of normally consolidated clay due to fill load.
2. Time (mos.) for 90% primary settlement to occur in clay

SOILS AND FOUNDATIONS WORKSHOP

SOLUTION TO EXERCISE NO. 4

1.Compute Primary Settlement

$$\Delta H = H \frac{C_C}{1+e_0} Log \frac{P_F}{P_0}$$

$$= 6\left(\frac{1.1}{1+2.10}\right) Log \frac{4400}{1500}$$

$$\Delta H = 1.0'$$

2. Compute Time for 90% Primary Settlement

$$t = \frac{T H_V{}^2}{C_V}$$

Double drainage as clay layer between two granular soils

$$H_V = \frac{6'}{2} = 3'$$

$$t_{90} = \frac{(0.848)(3)^2}{0.0175}$$

$$t_{90} = 436 \quad \text{Days or 15 Months}$$

Note: Time for any % of total settlement may be computed for this problem.

$$t = \frac{(3)^2}{0.0175} T = 515T$$